



On the Nature of the EUV Late Phase of Solar Flares

Ying Li

Collaborators: Mingde Ding, Yang Guo, Yu Dai

Nanjing University, China

June 2 2014



Contents

- Background
- Method
- Results
- Summary



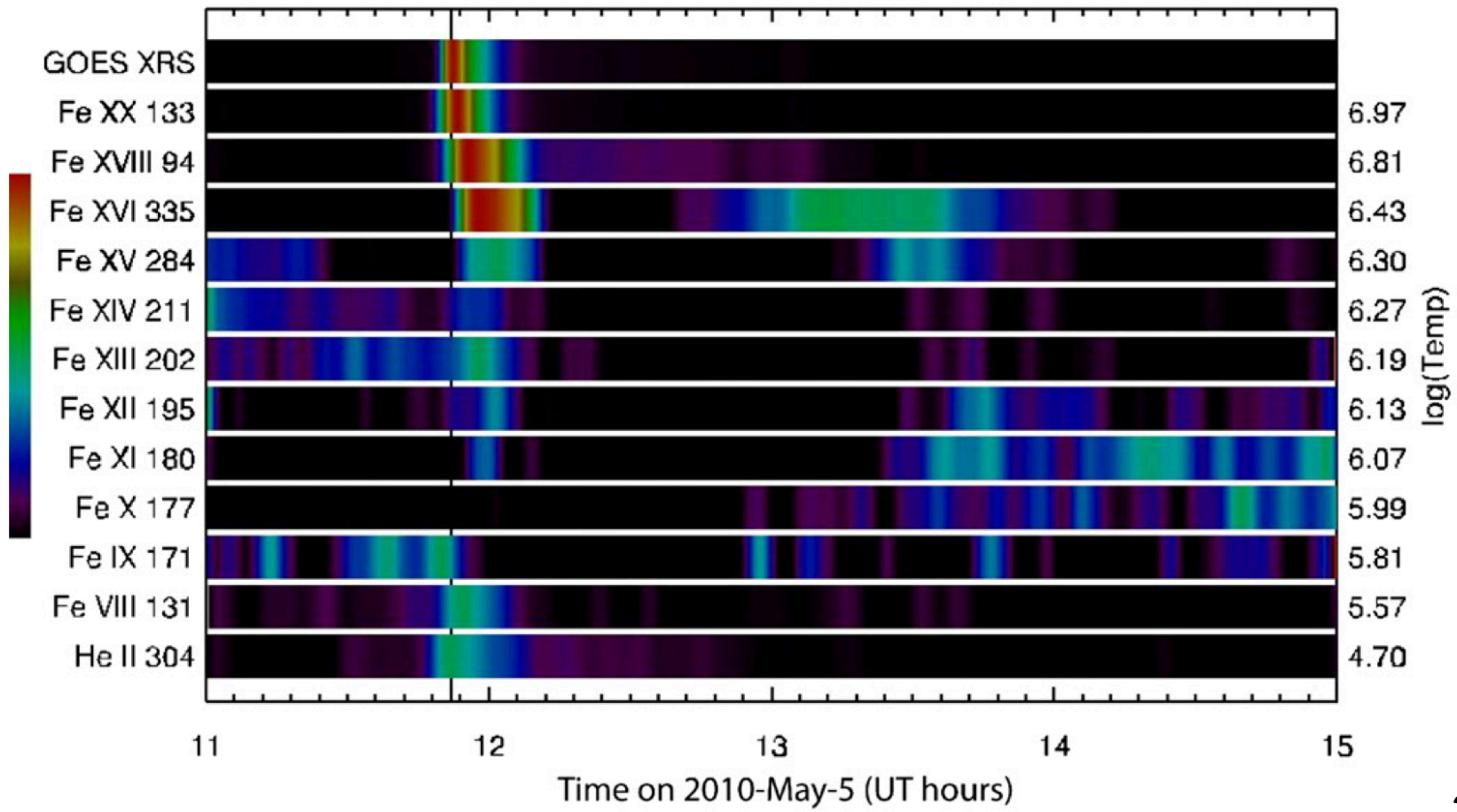


Background

The EUV Late Phase of Solar Flares

SDO/EVE EUV observations

(Woods et al. 2011)



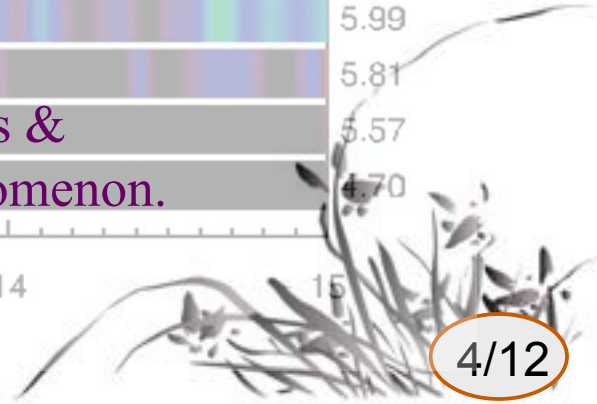
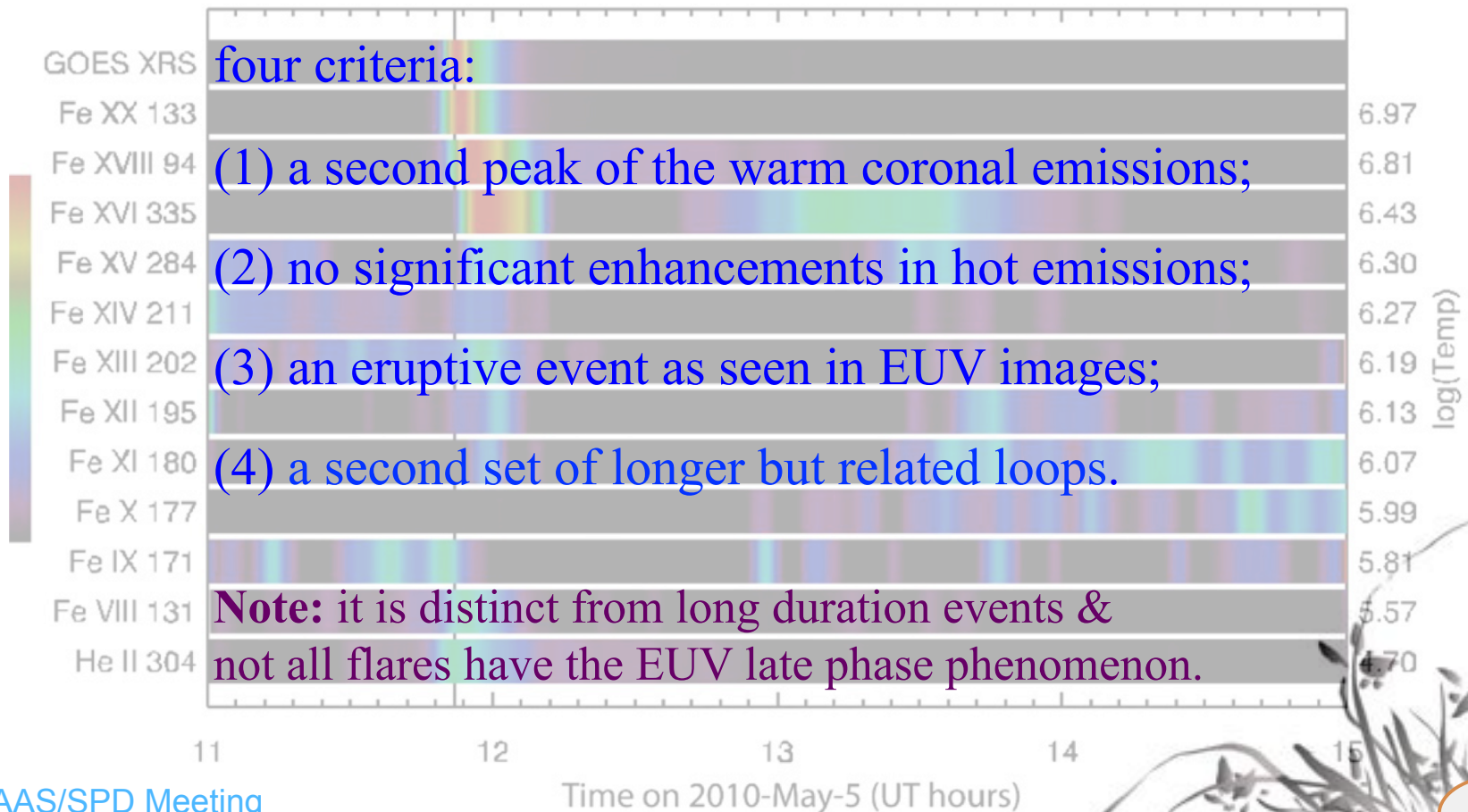


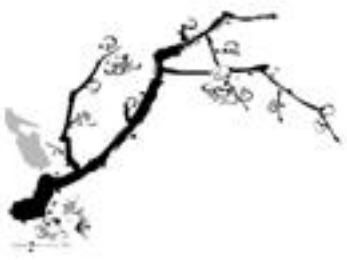
Background

The EUV Late Phase of Solar Flares

SDO/EVE EUV observations

(Woods et al. 2011)





Background

The EUV late phase emission comes from **the higher and larger loop systems (late phase loops)** rather than the main flaring loops.

Two physical explanations (mechanisms):

(1) an additional heating in the late phase loops;

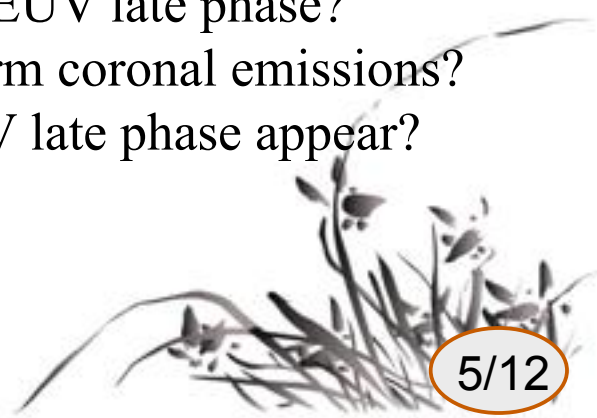
(Woods et al. 2011; Hock et al. 2012; Dai et al. 2013; Sun et al. 2013)

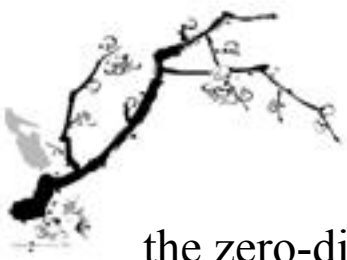
(2) the long-lasting cooling of the late phase loops.

(Liu et al. 2013; Sun et al. 2013)

Some questions ----- what we investigate in this work

- What roles do these two mechanisms play in the EUV late phase?
- Why does the EUV late phase show up in the warm coronal emissions?
- What does the magnetic configuration of the EUV late phase appear?



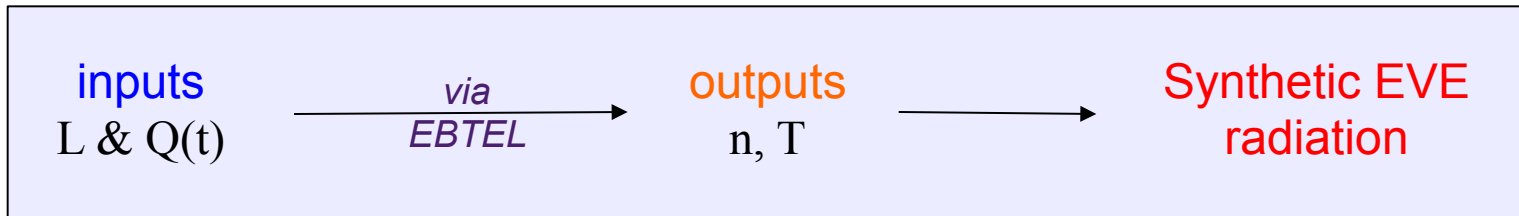


Method

the zero-dimensional “**E**nthalpy-**B**ased **T**hermal **E**volution of **L**oops” model (**EBTEL**; Klimchuk et al. 2008, Cargill et al. 2012)

$$\frac{dn}{dt} = -\frac{2c_2}{5k_B T} \left[\frac{F_c}{L} + c_1 n^2 \Lambda(T) \right]$$

$$\frac{dp}{dt} = \frac{2}{3} [Q(t) - (1 + c_1) n^2 \Lambda(T)]$$



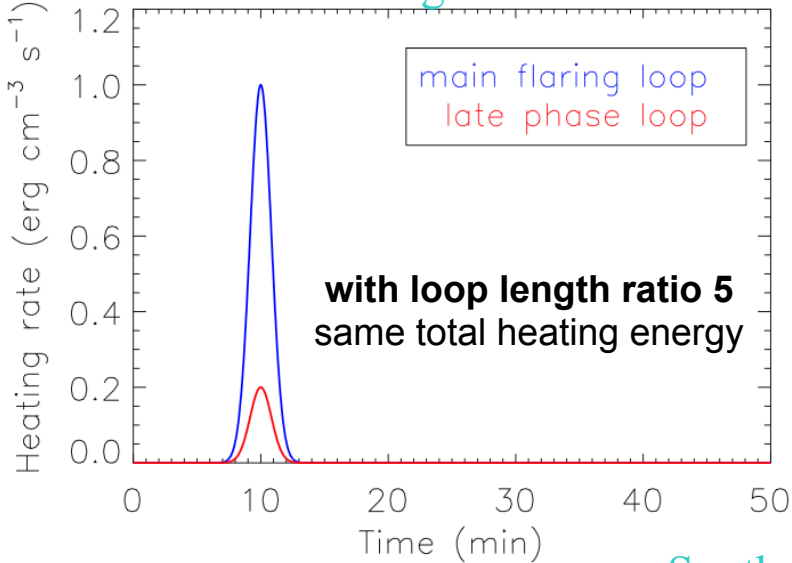
(Qiu et al. 2012; Li et al. 2012, 2014)

make systematic numerical experiments
based on observations, of course!!

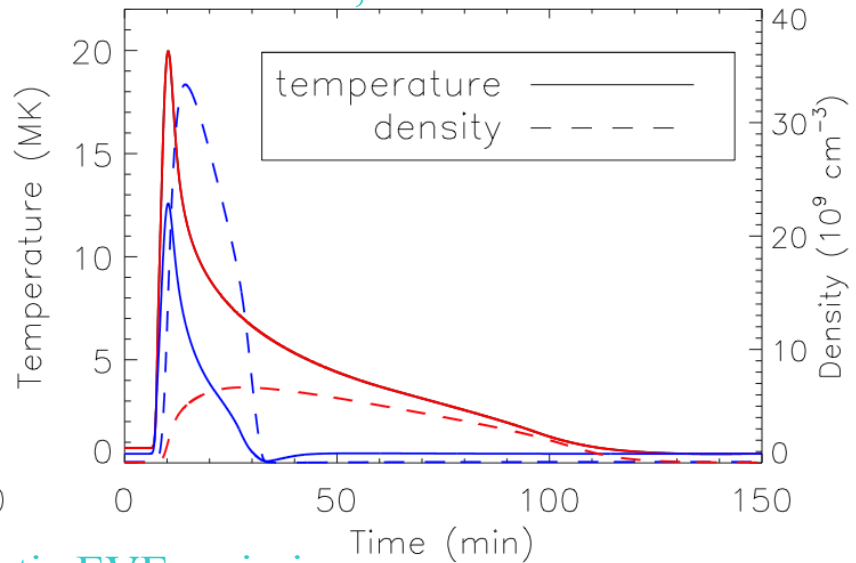


Case 1: main heating in two distinct flare loops

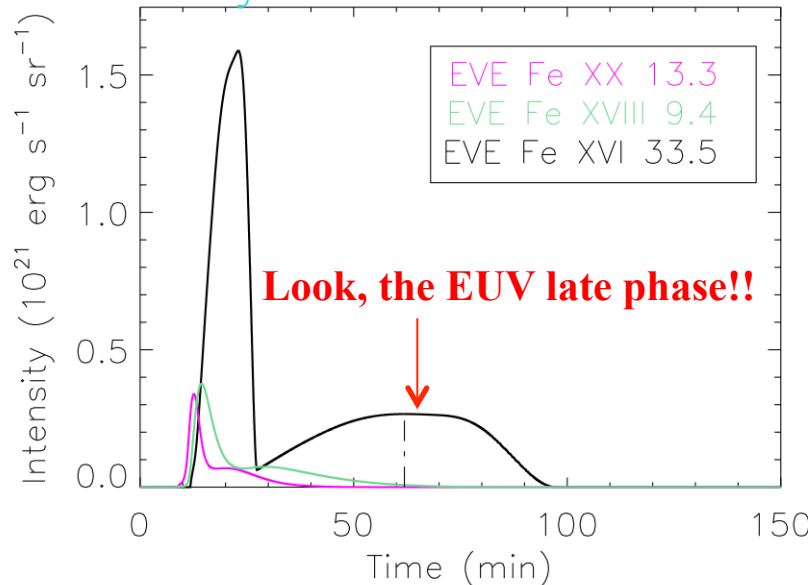
Heating function



T_e, n evolution



Synthetic EVE emission



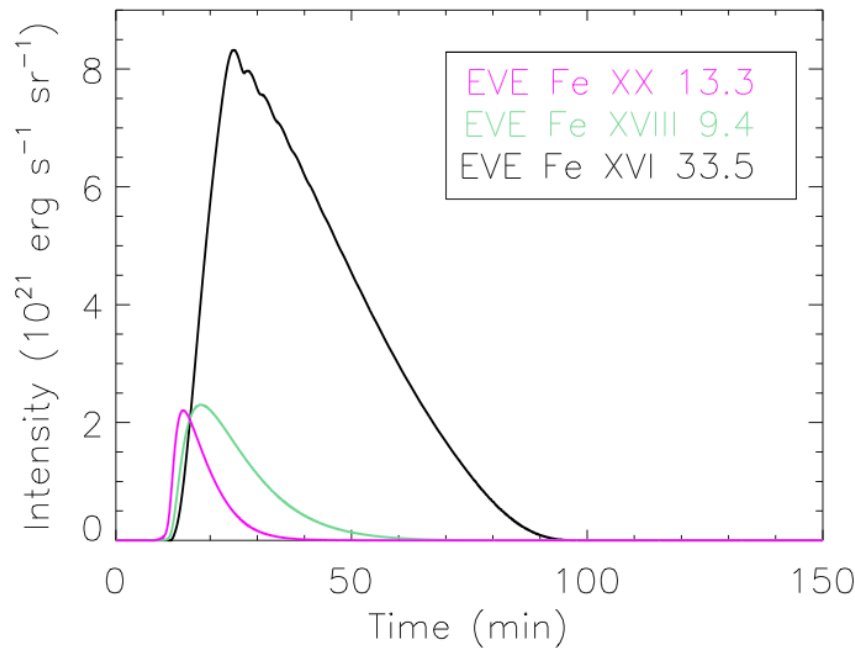
Only loop cooling which definitely exists, is sufficient to explain the EUV late phase!

The additional heating is unnecessary for the EUV late phase.

Case 2: main heating in a series of flare loops

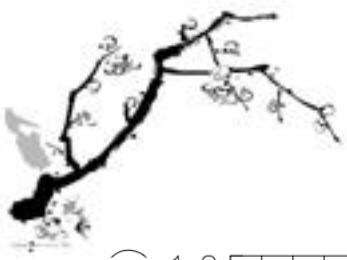
21 loops with lengths continuous distribution
the same total heating energy in each loop

Synthetic EVE emission



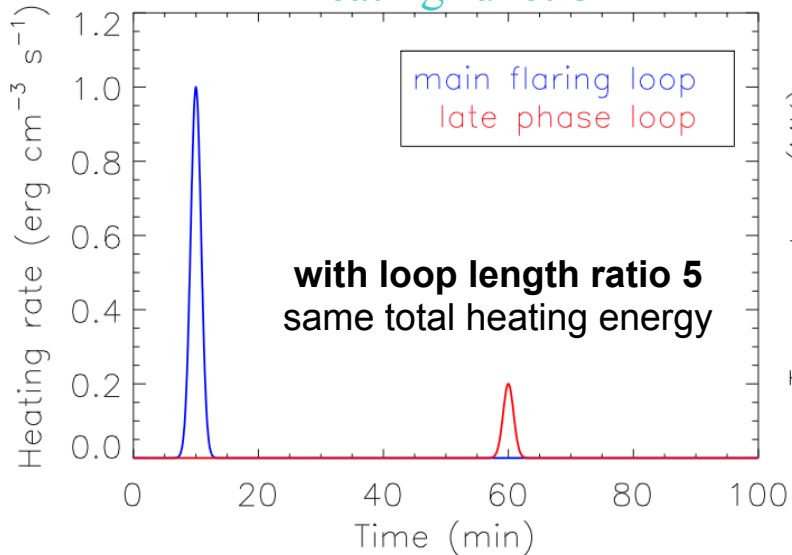
**No EUV late phase
shows up in this case!!**

A second set of longer loops
(long late phase loops)
are necessary in the loop
cooling scenario.

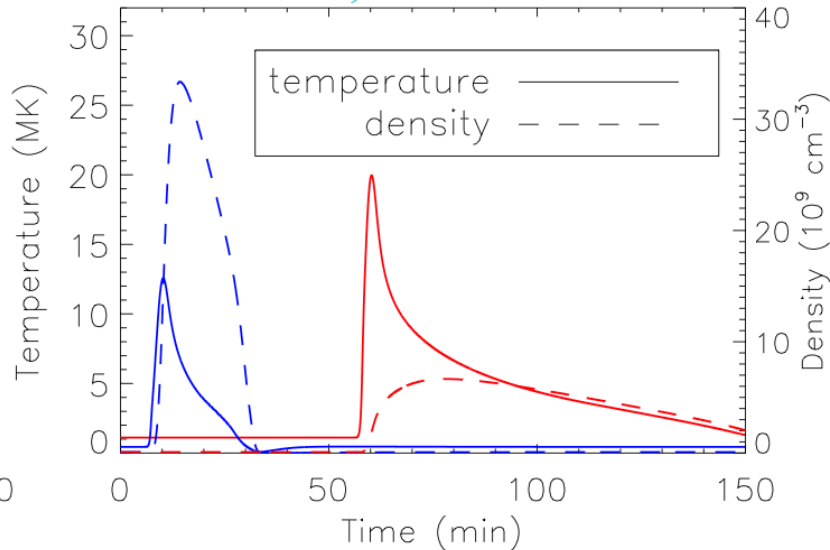


Case 3: main + additional heating in two distinct flare loops

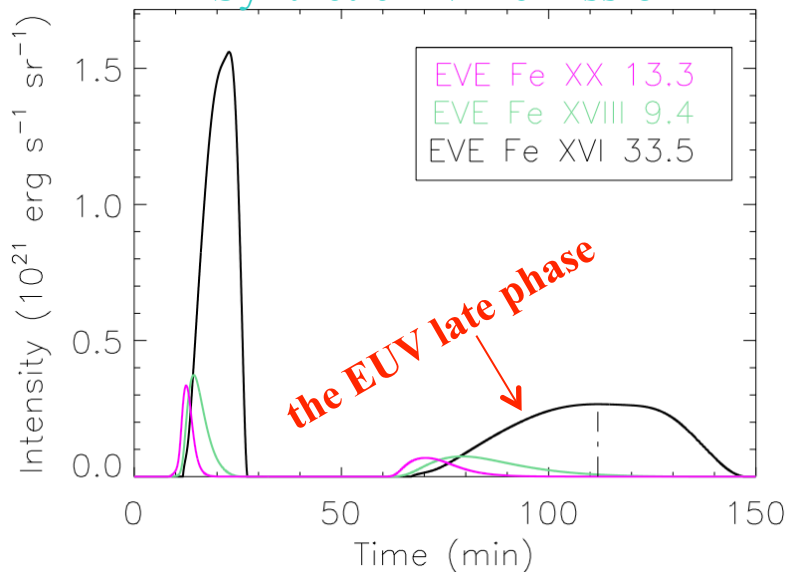
Heating function



T, n evolution



Synthetic EVE emission



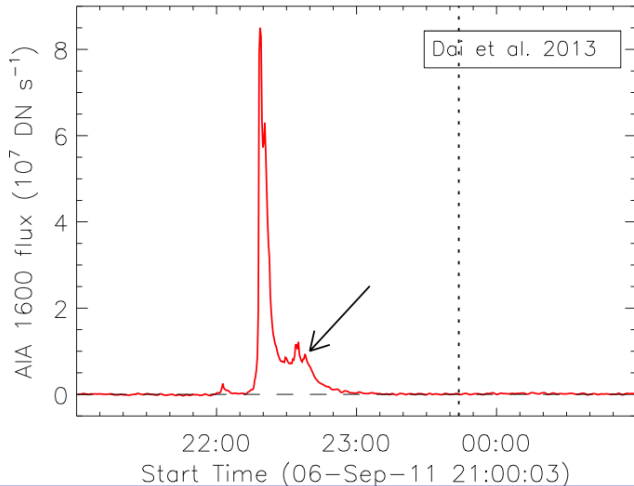
The additional heating is unnecessary, but plays a role in some events.



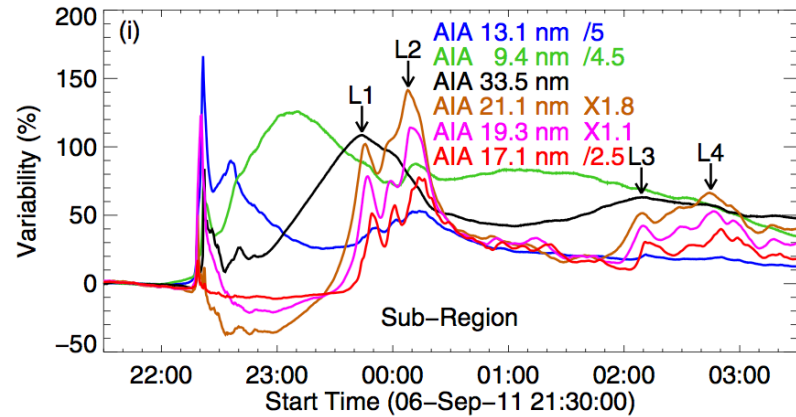
Observational hints for the additional heating

- (1) additional bumps (or long-time enhancement) *in the AIA UV 1600 light curve*
- (2) multiple peaks *in the AIA EUV emissions*

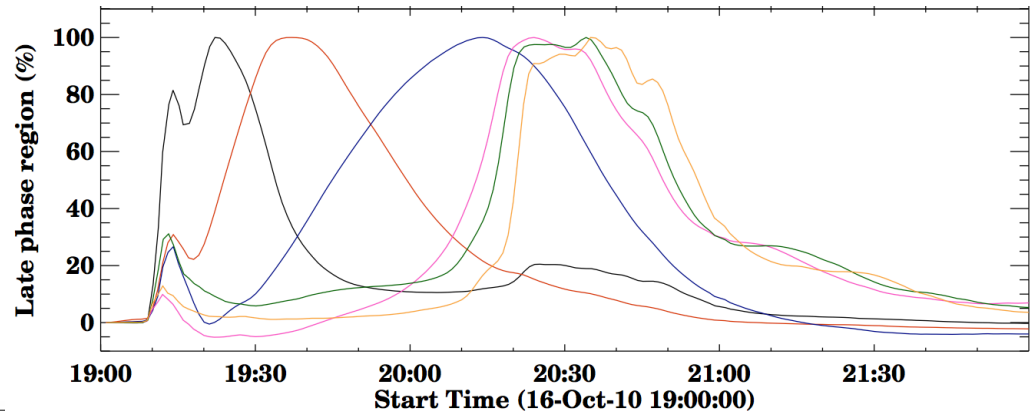
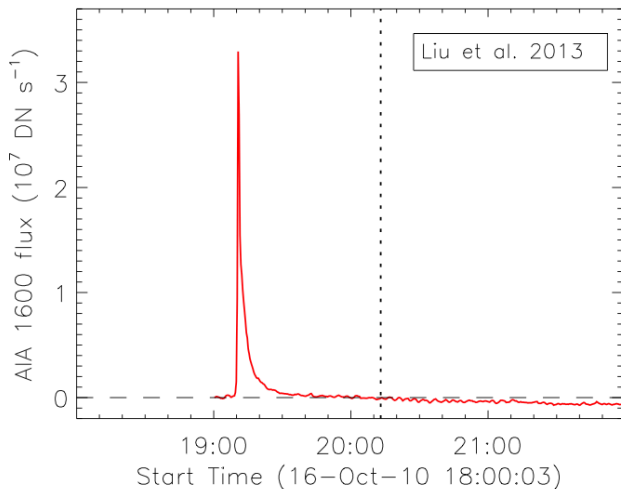
AIA UV 1600 light curve

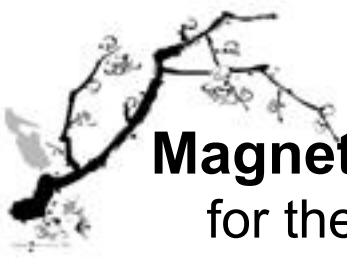


AIA EUV light curves



by comparison with long-lasting cooling





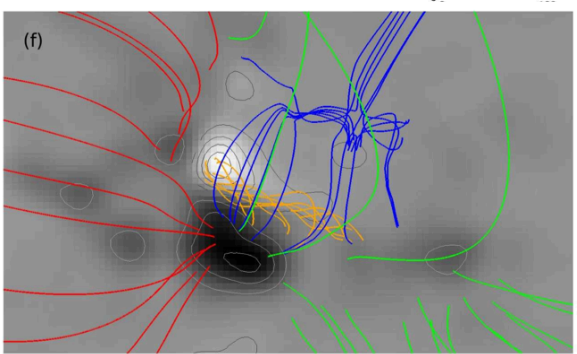
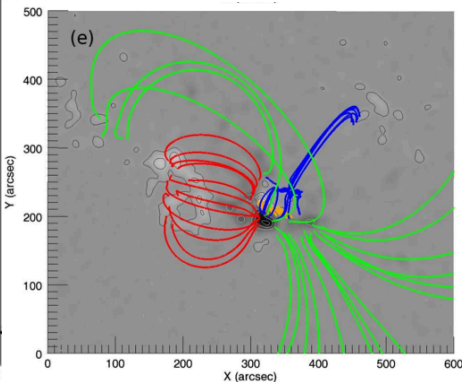
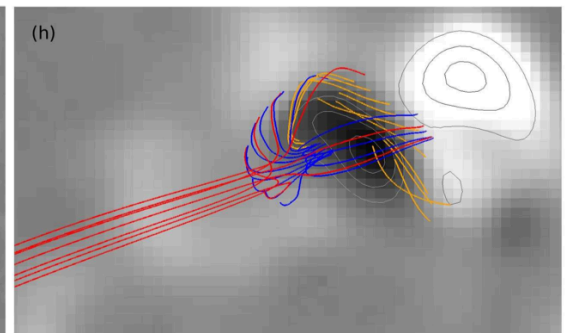
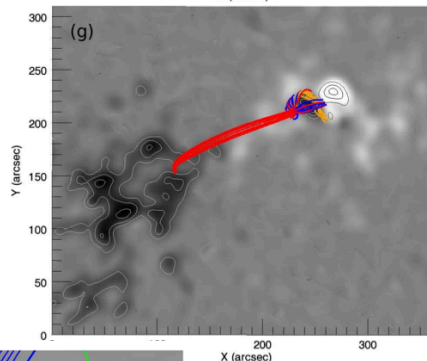
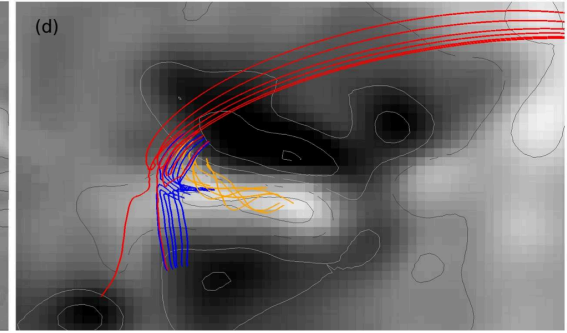
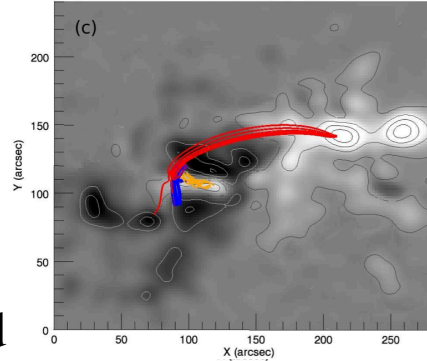
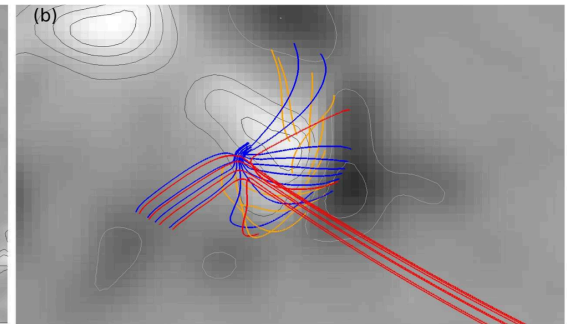
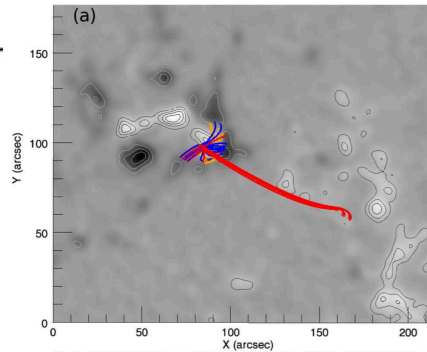
Magnetic configuration for the EUV late phase

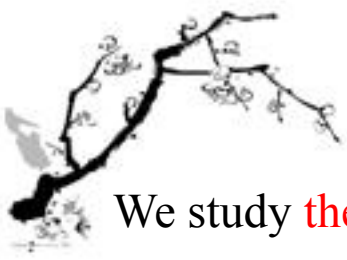
NLFFF modeling
red lines – late phase loops

spine field lines associated with a magnetic null point

OR

large-scale magnetic loops in multipolar magnetic fields





Summary

We study **the EUV late phase** based on **numerical experiments** & **SDO observations**.

The role of two mechanisms

- **long-lasting cooling**: definitely exists, sufficient to explain the late phase, preferable
- **additional heating**: may exist in some cases; two hints from observations

Magnetic configuration:

either spine field lines associated with a null point
or large-scale magnetic loops in multipolar magnetic fields

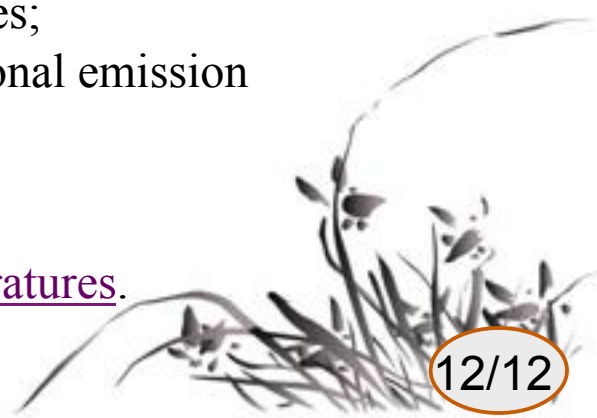
————— *dig more from the numerical experiments* —————

Why in the warm coronal emissions:

- Hot emissions are relatively weak and overlap with the main phase; (Liu et al. 2013)
- Warm channels are appropriate to separate the late phase emission;
- Late phase loops are only heated to the warm temperatures;
- Cool emissions are weak, and submerged in the bulk coronal emission

non-EUV-late-phase flares

- the flare loops with a continuous length distribution
- Two sets of flare loops are not heated to the warm temperatures.





Thanks for your attention!

